Chapter 9
Model Tests

9-1. General

Small-scale laboratory modeling of hydraulic structures (locks, dams, weirs, spillways, etc.) and vessels under open-water conditions is now common, and the modeling laws, criteria, and techniques are well established. The presence of ice adds serious complications to small-scale modeling because it adds a boundary at the top surface of the water body having different surface characteristics than the bed of the waterway. Moreover, whenever the mechanical properties of ice affect the problem under study, these must be duplicated in the model. The basic principle of dynamic similitude or modeling is to reproduce in the model the forces that govern the problem under consideration (gravity forces, inertia forces, viscous forces, shear forces, mechanical forces, etc.) in such a way that the ratio between any two forces in the model is equal to the corresponding ratio in the prototype. Except for a few cases, all these forces usually play some role in the actual physical phenomena of interest. Thus, strict adherence to the principle of dynamic similitude will lead to the conclusion that the phenomena can only be studied at full scale. It then becomes necessary to relax the principle of similitude, and to choose to model exactly only those forces that primarily affect the problem under consideration. Simultaneously, the “scale effects,” or errors introduced by imperfect modeling of the secondary forces, are held to a minimum by judicious model design. Therefore, it is important at the outset to correctly identify the primary forces that govern a particular phenomenon before attempting to study it in a physical model. This must be done to decide whether the necessary modeling techniques are available and how the model data can be extrapolated to full scale. In the present state of the art of ice modeling, phenomena that are strongly affected by heat transfer, e.g., refreezing of broken ice, icing of structures and the like, are not amenable to physical modeling.

9-2. Modeling Broken Ice

In phenomena that do not involve a solid ice sheet, but only ice floes, the main forces to consider are usually gravity forces, but also may include buoyancy forces, inertia forces, and possibly shear forces ascribable to water flowing underneath the stationary floes (e.g., ice held at a retaining structure such as an ice boom). If ice-on-ice friction is not considered to be critical, artificial ice floes can be used instead of real ice floes in the model, as long as the density of the material is equal to that of ice (e.g., polyethylene). The model study can then be made in an unrefrigerated facility with significant reduction in cost. An example of such a study is found in Calkins et al. (1982).

9-3. Modeling Sheet Ice

When the phenomenon to be studied involves the failure or breaking of an initially intact ice cover (e.g., ice forces on structures), the mechanical properties of ice (bending strength, crushing strength, shear strength, and ice friction) become important and must be properly modeled in the laboratory.

a. Model ice grown from a solution of salt or urea in water has been developed that can yield the required properties, as long as the model scale is greater than some limiting value. This limiting scale will depend upon the mode of failure of the ice sheet. (For example, the limiting scale is approximately 1:40 for ice failing in bending.) A refrigerated facility is necessary for this type of modeling. Discussion of a model study conducted in a refrigerated facility is given in Deck (1985) and in Gooch and Deck (1990).

b. Some artificial materials have been developed that are claimed to reproduce the properties of real ice, but their composition is proprietary, their handling is often messy, and even though they can be used in a warm environment, the cost of the experiments is similar to those in refrigerated facilities.

9-4. Model Calibration

Once a modeling technique has been chosen and the physical model built, it should be calibrated or verified. This process usually consists of the following steps: adjustment of bed roughness to reproduce the water surface profile without ice (this is the normal model verification for conventional hydraulic models); verification of head losses with simulated ice cover for known field conditions; and verification of the similitude of ice processes for known field conditions, such as ice breakup, ice drift pattern, and velocity. Even if this last verification is only qualitative, it is necessary to ascertain that the model is simulating observed natural phenomena. The objective of the calibration of a hydraulic model is to reproduce field conditions under more or less normal conditions, so that the model can be used to predict the effects of *abnormal* conditions or those produced by man-made changes with a good degree of confidence. In an ice–hydraulic model, it is not sufficient to reproduce water levels at various discharges as in a conventional hydraulic model. The ice phenomena also have to be correctly simulated. Many ice phenomena are not fully understood. If they are not carefully observed and documented at the particular field site to be modeled, it is unlikely that they can be simulated correctly in the model.

9-5. Model Distortion

While undistorted models, i.e., models with the same scale in both the horizontal and vertical directions, are by far preferable, distorted hydraulic models may have to be used when modeling long reaches of wide rivers. This is accomplished by exaggerating the vertical scale relative to the horizontal scale. The distortion does impose, however, a reevaluation of the roughness to be used in the model to correctly simulate the head losses occurring in nature. The distortion affects the scale of the thickness and mechanical properties of the ice to be formed in the model, as well as the extrapolation of the model test results to full-scale conditions. The distortion ratio, i.e., the ratio of vertical scale to horizontal scale, should be kept to a minimum and, under the present state of the art, no greater than 4 to 1.

9-6. Considerations in Choosing Modeling

While proper physical hydraulic modeling must follow some basic scientific and engineering principles, it still remains as much an art as a science. This is even more true when ice effects are involved. In this regard, the experience of the engineer in charge of a model study is a critical ingredient to the success of the study and to the reliability of its results. Physical modeling can be a very powerful tool in deciding among various potential designs for a project or among proposed solutions to a particular problem, in optimizing an initial design, in providing rational answers to objections to a proposed design or project, and in detecting potentially undesirable effects of a proposed design or solution, which may not have been foreseen otherwise, or not predicted by numerical modeling. While a physical model study often is a costly endeavor, when properly conducted, it can point the way to design or construction savings that often will more than offset its cost.

9-7. References

a. Required publications.
None.

b. Related publications.

Calkins et al. 1982
Calkins, D., D. Deck, and D. Sodhi. 1982. *Hydraulic Model Study of Port Huron Ice Control Structure*, CRREL Report 82-34, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire.

Deck 1985
Deck, D. 1985. *Cazenovia Creek Physical Ice Model Study*, Report to U.S. Army Engineer District, Buffalo, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire (unpublished).

Gooch and Deck 1990
Gooch, G., and D. Deck 1990. *Model Study of the Cazenovia Creek Ice Control Structure*, Special Report 90-29, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire.